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D. Robinson

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Combatant Protection and Nutrition Branch
Aeronautical and Maritime Research Laboratory

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ABSTRACT

The ADF has been using collapsible Petroleum, Oil and Lubricant (POL) tanks in Bougainville, Papua New Guinea for storage of diesel fuel. During usage, leakage was reported from the top surface of the tanks that were coated with a polyester urethane. The work detailed in this report covers an examination of the failed material and potential mechanisms to replicate the failure in the laboratory. Hydrolysis of the polyurethane coating was found to be the dominant cause of failure, with possible contributory effects from the manufacturing process.

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A Laboratory Study on the Failure of a Petroleum, Oil and Lubricant (POL) Fuel Tank

Executive Summary

The ADF used collapsible Petroleum, Oil and Lubricant (POL) tanks for storage of diesel fuel during operations in Bougainville, Papua New Guinea. While in service, leakage from the top surface of the tanks was reported. This report details an investigation undertaken to determine the causes of failure.

Infrared (IR) Spectroscopic analysis of the failed areas of the tank indicated degradation occurred as a result of hydrolysis of the coating. Laboratory investigations were undertaken in an attempt to replicate the failure mechanisms that occurred in-service. This involved accelerated weathering using a Xenon light weather-o-meter, dry light exposure, dry and water vapour saturated atmosphere exposure at an elevated temperature and a standard hydrolysis test using boiling 4% sodium hydroxide.

The tanks supplied to DSTO showed the areas mostly affected were located around the seams. As the entire upper surface of the tank is exposed this suggests that a precursor to failure occurred during manufacture. Although the manufacturing process was not examined, it was hypothesised that plasticiser was removed from the coating during the seaming process rendering the tanks more susceptible to degradation. This would need to be further verified with the manufacturer of the POL tanks.

Contents

1. Introduction

The Australian Defence Force (ADF) has been using polyurethane-coated collapsible fabric Petroleum Oil and Lubricant (POL) tanks to store diesel fuel during operations in Bougainville, New Guinea. During service it was reported that there was leakage (wicking) of fuel from the top of the tanks. This report details the findings of an investigation to determine the causes of failure.

1.1 Product quality requirement

The quality of POL tanks used by the Australian Defence forces (ADF) is governed by specification, MIL-T-52983G that requires the following requirements to be satisfied:

Coating

The coating shall be suitable for use with hydrocarbon fuels conforming to MIL-T-5624. The coating shall be resistant to weathering, ozone, ultraviolet light, use temperatures to 130 °F (54.4 °C), high humidity, and storage temperatures up to 160 °F (71 °C).

Coated fabric

The coated fabric shall be free from blisters or pinholes and shall show no signs of coating delamination. The coated fabric shall withstand the effects of humidity, high service temperature (130 °F/54.4 °C), ozone, and weather elements without damage, deterioration, or failure of meeting performance requirements.

Tank performance

The tank shall be suitable for use in continuous contact with rainwater, ground water, or water associated with fuel stored in the tank. There shall be no evidence of leakage or seepage from the tank when it is filled to its rated capacity of diesel fuel or jet fuel for **90 days**. The tank shall have a 10 percent minimum over capacity of fuel without rupture or evidence of weakened areas and without leakage or seepage of fuel. The tank shall be capable of withstanding an internal air pressure of 0.5 pound per square inch (psi) without evidence of leakage.

1.2 Observed failure

After months of service in the hot/humid climate of Bougainville the tanks were found to leak fuel around the seams and through their upper surfaces. Samples of undamaged, damaged and coated fabrics, used in the construction of the tanks were sent to AMRL-Maribyrnong to determine the cause of damage. Visual examination showed the external surfaces of the used tanks to be a darker brown than the undamaged fabric. It also showed severe degradation around the seams.

2. Test methodology

2.1 Identification

The tanks were manufactured from a woven nylon fabric, coated on both surfaces. Infrared (IR) spectroscopic analysis was used to identify the type of coating and to assist in identification of the material and where possible to identify any cause of failure.

2.2 Artificial light and weathering exposures

2.2.1 Xenon Light source

A Xenon light weatherometer was used to simulate in-the-field exposure. The weatherometer gives an accelerated exposure, with 5 to 9 weeks in the machine being equivalent to many times that in-the-field. The apparatus was programmed for continuous light and intermittent water spray which was designed to simulate accelerated weathering. A cycle of 102 minutes of light followed by 18 minutes of light and water spray was used. Specimen temperatures were recorded and remained at approximately 63°C black panel.

2.2.2 MBTF light source

The samples were also exposed under a Mercury Bulb Tungsten Filament (MBTF) light to examine the sensitivity response of the coated fabric to dry light radiation. Samples were exposed for a period of 32 weeks during which time one half of the sample was covered by a layer of aluminium foil, the other half was left exposed to the light source.

2.3 Hydrolysis

2.3.1 Incubator method

The propensity of the samples to hydrolyse was examined by exposing the samples in a desiccator partly filled with water to maintain a Relative Humidity (RH) of 100%. The desiccator was placed inside an incubator that maintained the temperature at 80 °C for the duration of the test.

2.3.2 Boiling sodium hydroxide

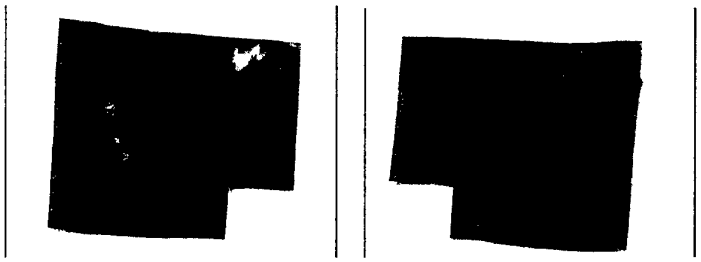
Samples were also tested for hydrolysis by boiling for 10 mins in a 4% solution of sodium hydroxide in accordance with specification DEF(Aust) 5023A part 4.13.2.[3] Extended boiling times of 30 minutes and 5 hours were also examined.

2.4 Diesel fuel immersion

A diesel fuel sample obtained from Bougainville was used to test the resistance of the coated fabric to diesel fuel. Fresh fabric samples were totally immersed in the fuel for 3 weeks at a room temperature that varied between 20°C and 38 °C.

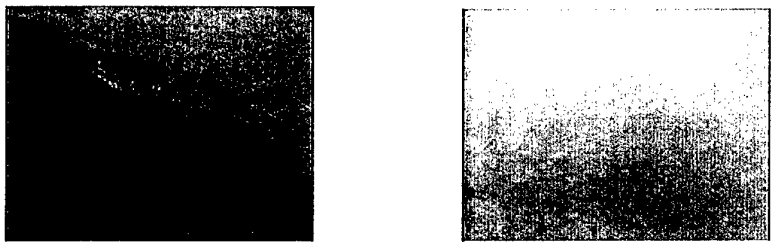
3. Results and discussion

Visual examination of the failed POL tank showed that the external section on the top coated surface was a dark coffee brown with several lighter coloured spots near the seams (Figure 1a). The internal upper surface was similar in colour (Figure 1b). The bottom external and internal sections of the tank were lighter in colour(Figures 2a, b) and showed no obvious signs of degradation. As only the top surfaces of the tank were exposed to sunlight the change in colour was attributed to Ultraviolet (UV) absorption by the pigment in the coating formulation. Similar colour changes were found in samples exposed to Xenon and MBTF light sources.



(a) External *(b) Internal*

Figure 1. Degraded POL tank coated fabric samples (top surface)



(a) External *(b) Internal*

Figure 2. A sample from the under side of the tank

3.1 Infrared (IR) Spectroscopic Analysis

Infrared spectroscopic analysis of the coating showed it to be an aliphatic-aromatic polyester-urethane [1]. Acetone solvent extraction was used to separate low molecular weight species of the urethane coating from the bulk. The acetone insoluble material was examined using IR spectroscopy and a comparison made between the relative amounts of polyester (soft segments) to urethane (hard segments). Coating samples from the undamaged fabric and from the bottom internal and external surfaces of an in-service tank showed the largest amount of polyester moiety. Samples from the badly degraded area (Figure 1), where both the tanks had ruptured, showed the least amount of polyester (approximately 50% loss). This indicates that the degradation process attacks the ester bonds, which decreases the molecular weight/physical properties of the polymer [1]. The decrease in the concentration of the ester moiety is consistent with a hydrolysis reaction.

3.1.1 Hydrolysis

It is well known that ester polyurethane is susceptible to hydrolysis through the ester linkage. The degree of hydrolysis is somewhat dependent on the crosslink density within the coating. In an attempt to simulate the failure mechanism that occurred in-service, samples of the coated fabric were tested for hydrolysis failure by boiling in a 4 percent aqueous sodium hydroxide solution for 10 minutes, 30 minutes and 5 hours respectively. The results were shown in Table 1.

Table 1. Hydrolysis of polyurethane coating

10 minutes	Fresh sample	No visible difference
30 minutes	Fresh sample	Visible change of colour on surface
	POL sample	Visible change of colour on surface
5 hours	Fresh sample	Visible change of colour on surface
	POL sample	Visible change of colour on surface

Boiling samples of the coated fabric in a sodium hydroxide solution did not degrade the coating to the same degree as observed in-service. It did have a significant impact on the colour of the coating, which changed from a light brown to grey (Figure 3). It was observed that the change of colour only occurred on the surface and did not penetrate the coating matrix.

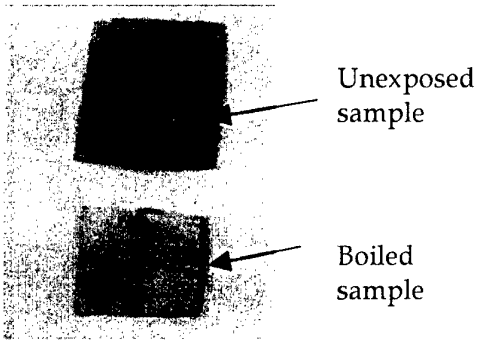


Figure 3. Change of colour after 5 hrs boiling in a 4% aqueous sodium hydroxide solution

3.2 Exposure to a MBTF light source

A sample of fresh fabric was exposed to a 500W MBTF light source for a period of 32 weeks. A photographic record of the exposed and unexposed sample is shown in Figure 4. Infra-red spectroscopic analysis indicated that no significant degradation of the sample occurred. The change of colour of the coating is most likely due to fading of the pigment within the coating.

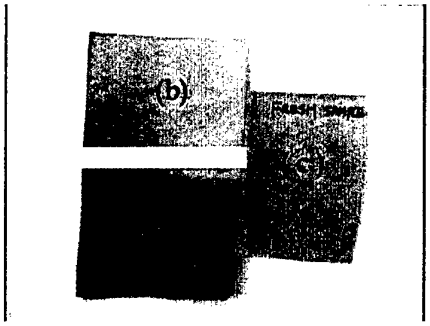


Figure 4. Sample subjected to MBTF light exposure (a) after 32 weeks, (b) unexposed and, (c) fresh sample

3.3 Exposure to a Xenon light source

According to the specification MIL-T-52983G [2], the POL tank fabric is required to be resistant to 1500 hours exposure under a Xenon light source when tested in accordance with ASTM D2565-92a.

Undamaged samples and samples from undamaged areas of the POL tanks were exposed in the Xenon arc weatherometer for periods ranging from 9 weeks for the undamaged sample and 5 weeks for samples from the POL tanks. Although the samples were exposed to both Xenon light and high humidity (water spray), apart from a change in colour, they showed no evidence of degradation. As shown in Table 2, IR analysis did not indicate any significant loss of ester moiety from the coating material. Figure 5 shows the rear and front faces of the internal and external surfaces of the tank after exposure to Xenon weathering. A sample of unexposed fabric is included for comparison.

Figure 6 shows an original sample of the coated fabric after 9 weeks exposure in the Xenon arc weatherometer. As expected, apart from a change in colour, there was no other visible damage to the specimen. This was confirmed by IR analysis and is shown in Table 2.

Table 2 Samples exposed to Xenon light and water spray

	Test duration	*Visual appearance*	*IR Spectroscopic Analysis*
Fresh sample	9 wks	Visible change of colour	No significant difference
POL tank sample	5 wks	Visible change of colour	No significant difference

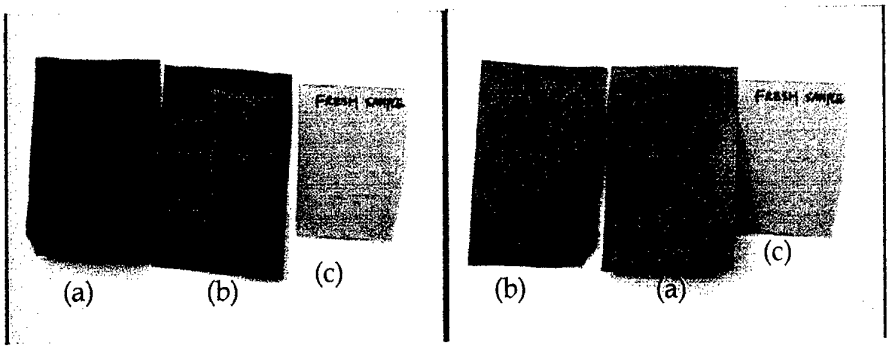


Figure 5. POL tank samples after 5 weeks Xenon light and water exposure (a) rear surface, (b) exposed surface and (c) unexposed sample

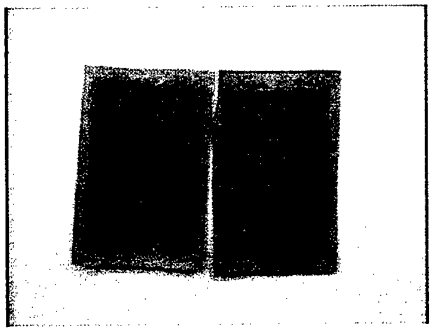


Figure 6. Fresh coated fabric samples after 9 weeks exposure to Xenon light and water spray

3.4 Hydrolysis-incubator method

Figures 7, 8 and 9 show the samples following exposure of 4, 6 and 12 weeks respectively in the hot and humid environment within the desiccator. Figure 7 displays visual evidence of water damage and Figure 8 shows the failure of the coated samples after 6 weeks exposure. Figure 9 shows that the sample was completely degraded after 12 weeks with cracks and delamination similar to the damaged areas observed in the in-service POL tanks. This suggests that a combination of a high temperature and high humidity over a period of time is necessary to completely hydrolyse the coating. This is reinforced when the visual appearances between a fresh sample and a sample exposed for 12 weeks in the dry environment within the

incubator are compared. As seen in Figure 10 there is little difference between the unexposed and exposed specimens, with no evidence of cracking or hardening of the coating. As no degradation of the coating was visible it was concluded that the coating is not susceptible to thermal degradation up to a temperature of 80°C.

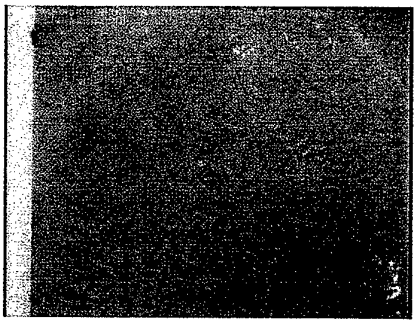


Figure 7. Sample after 4 weeks hydrolysis at 80°C and 100%RH

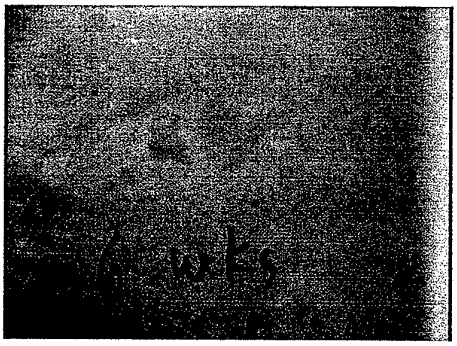


Figure 8. Sample after 6 weeks hydrolysis at 80°C and 100%RH

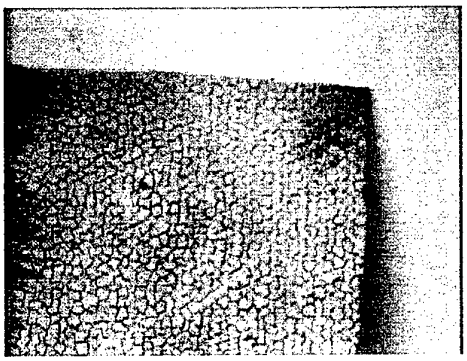


Figure 9. Sample after 12 weeks hydrolysis at 80 °C and 100%RH

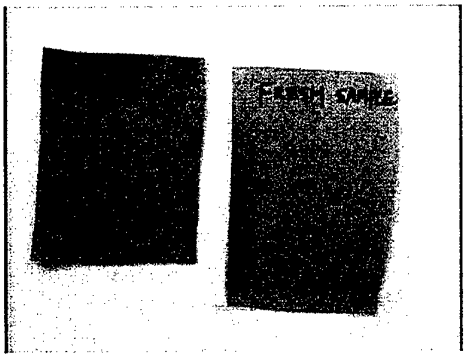


Figure 10. Sample after 10 weeks dry exposure at 80 °C

3.5 Effect of diesel fuel immersion

After immersion in diesel fuel for 3 weeks the samples showed a slight visible colour change (Figure 11). No cracks or delamination could be detected.

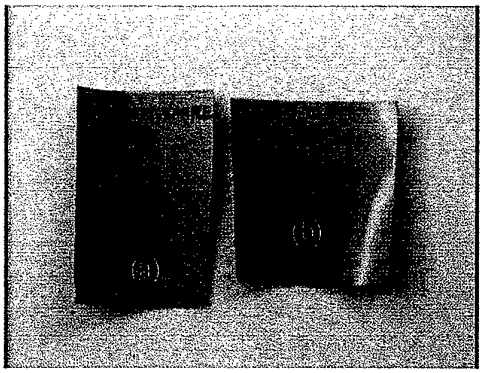


Figure 11. Unexposed coated fabric and coated fabric sample after 3 weeks immersion in diesel fuel (a) unexposed, (b) after immersion in diesel fuel

4. Conclusions

Coated fabrics, typical of those used to construct POL tanks have been subjected to a range of test procedures; including Xenon light irradiation, weathering exposure to a MBTF light source, thermal exposures up to 80°C, hydrolysis and IR analysis. These tests were designed to determine the causes of leakage failure observed in POL tanks used in New Guinea.

The only cause of failure of the coating was observed when fresh fabric samples were subjected to an environment of 80 °C and 100% R.H. for 4–12 weeks. The coated fabric performed well when:

(a) exposed to an MBTF light source.
(b) exposed to accelerated weathering under a Xenon light source.

This investigation concluded that the cause of failure appears to be hydrolysis of the coating caused by exposure to a high humidity combined with thermal radiation. Verbal information from the user stated that, when in-service, the tanks developed leaks across the top surface. The tanks provided to AMRL-M for analysis showed the majority of the damage confined to areas around the seams. As the entire upper surface of the POL tank is exposed to the environment, failure should not be confined to a specific area. It is possible that the areas around the seams are more susceptible to failure due to the processes used to form the seams. Further work is required to verify this with the manufacturer of the POL tank.

5. References

1. Mathys, G., Failure of POL fuel tank, Test report, CSS 4/2-12, 99/65, 1999.
2. MIL-T-52983G, Military Specification, Tanks, Fabric, Collapsible, 1998.
3. DEF(Aust) 5203A Specification, Cloth, Coated; (Plain Weave), 1992

6. Acknowledgments

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